# 120 years of very fast fluctuations

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*In December 1888, the great German physicist Heinrich Rudolf Hertz completed the basic experiments on the discovery of electromagnetic waves, later called radio waves. The indicated date is celebrated as one of the most important scientific and technical events in the history of physics.*

## Light speed measurements

Even before our era, many scientists in the field of natural science and philosophy (at the time of broad concepts, including physical knowledge) knew a number of properties of light: the direct divergence of rays; their reflection from the mirror at an angle equal to the angle of incidence; refraction in water; propagation significantly faster than sound; a rainbow phenomenon in the sky, explained by the scattering of a large number of drops of water passing through itself and reflecting the sunshine.

The first to measure the speed of light was set in 1607 by the Italian philosopher, mechanic and astronomer G. Galileo (1564-1642). Having placed the assistants in the hills with the lanterns lit and covered with shutters, at a distance of 1.5 km from one another, he asked them to open the shutters as quickly as possible, if they saw the light from the neighbor's lamp. Galileo puzzled himself by determining the time of passage of light departures along the chain. The experience was very naive and therefore unsuccessful.

An elegant and truly scientific experiment in measuring the speed of light [1] was put in 1675 by the Danish astronomer O. Roemer (1644-1710). By that time, the satellites of Jupiter, discovered by Galileo in 1609, had already been observed. It was known that the satellite Io fell into the shadow of the planet every 42.5 hours. However, the onset of eclipses of the satellite visible from the Earth by Jupiter differed from the calculated ones and depended on the position of the Earth in outer space, which It seemed there shouldn't have been. The error reached 22 minutes, when the Earth moved in its orbit from Jupiter to the maximum distance. Roemer suggested that light reflected from a celestial body makes a mistake, propagating with finite speed. At that time, the parameters of the orbits of the Earth, Jupiter and its satellites were not exactly known, so the found speed of light turned out to be equal to 222,000 km / s.

The English physicist and talented inventor C. Wheatstone (1802-1875) in 1834 assembled a device for measuring the speed of light indoors, in which he used three Leyden banks that served as sources of light discharges. In front of them, he mounted a thin and light rotating mirror. Using the merging lines from light sources, he determined the resulting number of revolutions of the reflector, after which he calculated the speed of light rays passing a known distance. In modern literature, Wheatstone reported a result of 464,000 km / s.

However, Wheatstone is better known for his involvement in the famous bridge measuring electrical resistance. His real inventor is the English scientist-researcher of terrestrial magnetism and mathematician S. Christie (1784-1865), who proposed the device in 1833. Whitston became famous for the popularization and energetic promotion of the bridge during the construction of the telegraph, in educational and laboratory practice.

The measurement of the speed of light in "ground" conditions [1] on the outskirts of Paris was carried out by the French physicist A. Fizeau (1813-1896) and his father in 1849. A light source and a reflective mirror were installed at a distance of 8.66 km from each other. A gear wheel with 72 teeth modulating the light beam was placed between them. By the maximum intensity of light radiation "by eye" was determined by the rotation speed of the mechanism (25 s-1). After that, the intervals of succession of reflected flashes were calculated. The distance covered by the beam (17.32 km) was divided by the duration of the light flash. The result was 312,000 km / s, close to the current value with a relative error of 4.072%.

The next one, who wanted to measure the speed of light in 1850, was also the French physician, physicist and astronomer J. Foucault (1819-1868), who repeated the Fizeau setup, but replaced the gear in it with a rapidly rotating mirror [1]. It made it possible to reduce the path of a light beam to 20 m and carry out measurements in laboratory conditions. The result obtained in 1862 of 298,000 km / s turned out to be noticeably closer to the true value with an error of 0.6%. In addition to the rotating reflector, Foucault placed a glass tube filled with water next to him and showed a characteristic decrease in the speed of light propagation in another medium.

In 1878, the French professor of physics M. Cornu (1841-1902) decided to continue experiments on measuring the speed of light. Cornu returned to the Fizeau gear, in which he increased the number of teeth to 200. His result corresponded to 300,000 km / s (0.069%).

At the end of 1877, an American naval officer and engineer A. Michelson (1852-1931) started a particularly accurate measurement of the speed of light, publishing the first result in April 1879 (300,092 km / s, 0.1%). And he devoted his subsequent life to measuring the speed of light. For performing large-scale precision work, the scientist was awarded the Nobel Prize in 1907. The last measurement he took in 1924 was completed in 1933, after his death [1]. The result based on 2885 measurements is 299 774 km / s (0.006157%).

The current value of the speed of propagation of light and electromagnetic waves in a vacuum (fundamental physical constant) is 299792458 m / s.

# Experiments with the light of M. Faraday

On March 12, 1832, M. Faraday (1791-1867) sends a letter of prophecy to the British Royal Society (analogous to the Imperial Academy of Sciences in Russia), entitled "New Views, currently to be stored in a sealed envelope in the archives of the Royal Society" [2]. Discovered and studied only in 1938, the document contains clairvoyance: "I have come to the conclusion that the propagation of magnetic influence requires time, which, obviously, will be very small. I also believe that electric induction propagates in exactly the same way. I believe that the propagation of magnetic forces from the magnetic pole is similar to the vibrations of an agitated water surface ... By analogy, I believe it is possible to apply the theory of oscillations to the propagation of electrical induction ... Currently, as far as I know, none of the scientists except me, he has no such views. " Nevertheless, Faraday discloses the contents of the letter later, in 1845, in the published 19th series of his scientific diary "Experimental Studies in Electricity" [3, p. 50-52], and even later, on April 15, 1864, in the letter "Thoughts on Radiation Oscillations" [3, p. 53-57].

Faraday began the final work on determining the relationship of light and electromagnetic forces at the end of 1845. It is believed that on Saturday September 13 of that year, he and his assistant conducted a key experiment that served to establish and develop the electromagnetic theory of light and invisible fast vibrations. The experience was that between the poles of a fairly powerful electromagnet they placed a rectangular piece of very clean glass, made according to the recipe of Faraday himself. He was well aware that in a glass a ray of light is refracted and to a large extent becomes polarized. When an electric current was passed through the winding of the electromagnet, a change in the position of the plane of polarization of light was observed. The phenomenon disappeared when the current was turned off. In the following months, Faraday set up a series of similar experiments.

The German mathematician, astronomer and physicist K.F. Gauss (1777-1855) together with another German physicist V.E. Weber (1804-1891) from 1832 developed a system of units of measure of GHS (centimeter, gram, second), hereinafter operating everywhere until almost 1960 (since 1889, in parallel with the ISS - meter, kilogram, second), when the international SI system was adopted. In some areas of science, the GHS system is still in effect. They proposed to bring magnetic units to electrical ones through the speed of light. To do this, we calculated the charge of the capacitor (Leyden jar) in electric and magnetic units and found that their ratio is determined by the speed of light.

In 1846, Weber pointed out the ordered movement of electric charges in a conductor at high speed. Ten years later (1856), he, together with the German physicist R. G. Kolrausch, conducted an experimental check of the speed of movement of charges in a thin metal wire. It turned out that it is close (310 740 km / s) to the speed of light.

Faraday in the abovementioned letter (1864) refers to the speed of propagation of electricity in wires according to the experiments of Wheatstone known to him, measured shortly before and approximately equal to 190,000 mph (305,775 km / s). The works performed by Weber, Kohlrausch, and Wheatstone in the second half of the 19th century, for the scientific world served as an unconditional indication of the commonality of optical, electrical and magnetic natural phenomena.

## Dynamic Maxwell Theory

While still a very young man in the early 1850s, the English theoretical physicist J. C. Maxwell (1831-1879) began to study the published laboratory journal Faraday "Experimental studies on electricity" (1831-1846). Subsequently, in the preface to the first edition of his most important work, A Treatise on Electricity and Magnetism (1873), Maxwell wrote: “Before I started studying electricity, I decided not to read mathematical works on this subject until I thoroughly I will read the Faraday "Experimental Studies"; “Perhaps science benefited from the fact that Faraday, mastering perfectly the basic concepts of space, time and force, was not a professional mathematician”; “But by doing so he retained wider freedom for his own work, to coordinate their ideas with the facts discovered by him and to express their thoughts in a natural, non-technical language ”; “Mainly in the hope of making his ideas the basis of mathematical theory, I undertook to write this treatise”; “I limited myself almost exclusively to the mathematical presentation of the subject” [3, p. 105-111].

Since the beginning of the last millennium, and especially in the 17th-19th centuries, the theory of long-range or instantaneous action at a distance of electric and magnetic forces has dominated in European countries. The strength of its position was not affected by the measurements of light speed carried out by scientists. In the works Faraday Field Lines (1857), The Dynamic Theory of an Electromagnetic Field (1864) and Treatise ... Maxwell announced that electromagnetic waves propagate at a finite speed of light and introduced the concept of field . In the introduction to the "Dynamic Theory ..." he explained: "An electromagnetic field is that part of space that contains and surrounds bodies in electrified or magnetized states; the theory that I propose can thus be called the theory of the electromagnetic field ”[3, p. 73]. Further in the 20th paragraph [3, p. 78, 79], he writes that in the field “only those perturbations can be propagated that are transverse with respect to the propagation direction, and that the propagation velocity is so close to the speed of light that we have, apparently, good reason to conclude that light (including radiant heat and various other radiation) is an electromagnetic disturbance in the form of waves propagating through an electromagnetic field according to electromagnetic laws ”; “The concept of the propagation of transverse magnetic disturbances, with the exception of the possibility of longitudinal disturbances, was clearly expressed by Professor Faraday in his Thoughts on Radiation Oscillations.” The electromagnetic theory of light, proposed by him, is essentially the same that I began to develop. " which are transverse with respect to the direction of propagation, and that the propagation speed is so close to the speed of light that we have, apparently, good reason to conclude that light (including radiant heat and various other radiation) is an electromagnetic disturbance having the form waves propagating through an electromagnetic field according to electromagnetic laws ”; “The concept of the propagation of transverse magnetic disturbances, with the exception of the possibility of longitudinal disturbances, was clearly expressed by Professor Faraday in his Thoughts on Radiation Oscillations.” The electromagnetic theory of light, proposed by him, is essentially the same that I began to develop. " which are transverse with respect to the direction of propagation, and that the propagation speed is so close to the speed of light that we have, apparently, good reason to conclude that light (including radiant heat and various other radiation) is an electromagnetic disturbance having the form waves propagating through an electromagnetic field according to electromagnetic laws ”; “The concept of the propagation of transverse magnetic disturbances, with the exception of the possibility of longitudinal disturbances, was clearly expressed by Professor Faraday in his Thoughts on Radiation Oscillations.” The electromagnetic theory of light, proposed by him, is essentially the same that I began to develop. " good reason to conclude that light (including radiant heat and various other radiation) is an electromagnetic disturbance in the form of waves propagating through an electromagnetic field according to electromagnetic laws ”; “The concept of the propagation of transverse magnetic disturbances, with the exception of the possibility of longitudinal disturbances, was clearly expressed by Professor Faraday in his Thoughts on Radiation Oscillations.” The electromagnetic theory of light, proposed by him, is essentially the same that I began to develop. " good reason to conclude that light (including radiant heat and various other radiation) is an electromagnetic disturbance in the form of waves propagating through an electromagnetic field according to electromagnetic laws ”; “The concept of the propagation of transverse magnetic disturbances, with the exception of the possibility of longitudinal disturbances, was clearly expressed by Professor Faraday in his Thoughts on Radiation Oscillations.” The electromagnetic theory of light, proposed by him, is essentially the same that I began to develop. " with the exception of the possibility of longitudinal disturbances, was clearly expressed by Professor Faraday in his Thoughts on Radiation Oscillations. The electromagnetic theory of light, proposed by him, is essentially the same that I began to develop. " with the exception of the possibility of longitudinal disturbances, was clearly expressed by Professor Faraday in his Thoughts on Radiation Oscillations. The electromagnetic theory of light, proposed by him, is essentially the same that I began to develop. "

Maxwell developed the theory of the electromagnetic field and the fundamental equations expressing it in 1860-1865. In a popular form, they are presented in [2, 4]. Russian physicist theorist L. I. Mandelstam (1879-1944) in the introduction to [3, p. 24], emphasizing the main point of the theory and explaining the first equation, he wrote that in Maxwell's mathematical theory "Faraday's induction law is expressed in terms of field theory so that the rate of change of the number of magnetic lines passing through the circuit is proportional or, more precisely, more precisely , defines the integral over the contour of the electromotive force that arises at the same time ... Adopting this in his theory, Maxwell takes the next decisive step, which belongs entirely to him. He postulates the reciprocity between electric and magnetic fields, suggesting that the rate of change in the number of electric field lines, penetrating the surface of a closed loop, in turn, generates a magnetomotive force in the loop, the integral of which is proportional to the rate of change in time of the flow of electric lines, ie, the bias current, which is equivalent, therefore, to the normal current in the conductors. " Or else it can be said that the conductor crossing the electric power lines with a certain speed generates, in turn, a magnetomotive force in the circuit, proportional to the rate of change in the flow of electric lines over time, equivalent to the usual current in the conductors.

However, the terms "electromagnetic wave" and "wavelengths" of light, defined in 1801 by the Englishman T. Jung (1773-1829), are not found in the works of Faraday and Maxwell, there are no direct indications of the possible presence in nature of other electromagnetic waves that differ from light number of oscillations per unit time. Formally speaking, Maxwell did not predict high frequency electromagnetic disturbances invisible to the eyes, propagating in the ether at the speed of light. His followers theoretically proclaimed their existence as an axiom, although they did not understand why they would be needed. The phenomenon of self-induction, known since 1832, as a special case of electromagnetic induction, was used by Faraday in separate experiments, but in his written works there is no mention of the term

It is hard to believe that gifted scientists did not know the super-genius theoretical and practical formula for calculating the self-induction EMF developed by the Russian physicist E. Kh. Lenz (1804-1865) as early as 1833: $E = -L * di / dt$. It also seems unbelievable that they were not familiar with the resonance and the other, which was deduced by the Irish physicist W. Thomson (1824-1907) in 1853 with an equally remarkable formula: $T = 2\pi\sqrt{LC}$. It should be noted that it is the phenomena of self-induction, resonance, and these formulas that served as the basic physical direction, which received the name "radio engineering" in the 20th century.

In the well-equipped and well-known Cavendish Laboratory of British University of Cambridge, headed by Maxwell, since its creation in 1871, no attempts have been made to verify the provisions of the open electrodynamic theory. However, it is known that Maxwell was not in captivity of the "pure theorizing" divorced from life. He did some applied work, for example, proposed a method for obtaining color photographs, and invented a tool to remove grease stains from clothes.

Maxwell did not meet with Faraday. Only in October 1861 did he notify him in writing of the most important revelation that formed the basis of the "Dynamic Theory of an Electromagnetic Field" prepared for publication: "Light consists of transverse waves of the same medium that causes electric and magnetic phenomena." Faraday highly appreciated the message, supported Maxwell.

## Secret becomes apparent

At the end of the XVIII - the first half of the XIX centuries, the most successful scientific experiments were conducted in France. In the second half of the XIX century, Germany was considered the scientific center of Europe. The most important scientific and technical materials began to be published in German, right up to the outbreak of World War II. Many popularizers of the achievements of science even proclaimed that the Germans had discovered everything and there was nothing to invent.

The dominant theory in European minds of instantaneous action (long-range) explained, it would seem, all the physical processes associated with electricity and magnetism. The most prominent scientists in Germany have written most of the "deep" and "substantiated" works that mathematically support the theory. Maxwell's electrodynamic postulates and his equations did not fit into this theory. Leading German physicist and physiologist G. von Helmholtz (1821-1894) even laughed at the wise men from England, Maxwell and Faraday.

However, European physicists already knew about the practical implementation of some of the ideas of Faraday. It was impossible to dismiss them. In Russia, academician-electrician B.S. Jacobi (1801-1874) together with Lenz in 1838, in Italy, physicist-electrician A. Pacinotti (1841-1912) in 1860, electric motors suitable for operation were proposed. In England, the telegraph engineer K. Varley (1828-1883) in 1866 and Whitston in 1867, in Germany the engineer-inventor V. von Siemens (1816-1892) in the same 1867 developed workable electric current generators. Along with this, physicists published materials on their observations of fast electrical vibrations that occur, for example, during the discharge of Leiden cans.

In 1826, for the first time, the French physicist F. Savary (1791–1841) made a statement on the vibrational discharge of a capacitor storage of electricity. The American physicist J. Henry (1797-1878) in 1842, and in 1847 Helmholtz himself also instrumentally observed spark oscillations decaying at high speed from a Leiden can. In 1857, the German physicist W. Feddersen (1832-1918), using the research method borrowed from the Englishman Wheatstone, studying the images of sets of sparklight visible in a rotating mirror, measured the period of the main oscillation, equal to 5 μs. He further confirmed the "vitality" of Thomson's formula for the frequency of oscillations in the circuit, depending on the values of inductance and capacitance. The experiments showed that from the invented by the German G. Rumkorf (1803-1877) high-voltage coil (1851

The experimental results indirectly confirmed the assumptions made by Maxwell about the presence of electromagnetic disturbances, differing in wavelength from light, but having the same nature and speed of propagation. Under the pressure of evidence, Helmholtz developed a compromise and, as shown by the future, far-fetched theory of the duality of electric forces - electrodynamic, transmitted at the speed of light, and electrostatic, acting on charged bodies inertialessly (instantly).

In 1879, Helmholtz drew the attention of his best student G. R. Herz (1857-1894) to the competition work of the Prussian Academy of Sciences, devoted to "experimental proof of the presence of any connection between the electrodynamic forces and the dielectric polarization of insulators" [3, p. 112]. Obtaining a positive or negative result would essentially mean recognition or refutation of the Maxwell-Faraday electrodynamic theory. Hertz carried out the calculation of the vibrational frequency necessary for the experiment and decided that the experiment is unlikely to produce a pronounced effect when using the Leiden cans and induction pathogen that he had. He remembered the task, but he managed to start solving it only in the autumn of 1886, being an extraordinary professor at the Higher Polytechnic School in Karlsruhe (Germany, Baden-Württemberg).

Later, in 1891, in the collection of his articles under the general title "Research on the propagation of electric force", in the introductory review [3, p. 112-130], Hertz wrote that in the institution's laboratory he was attracted by inductors capable of generating a spark discharge from switching with small Leyden banks or galvanic batteries. Seeing the "violent" and regular electrical vibrations, he found them suitable for solving the problem of the Prussian Academy.

Hertz noted "another special and unexpected property of an electric spark, which was not envisaged by any theory." Thanks to spark flashes, the still invisible "electric motions were excited, faster than those that physicists had before". Hertz "even doubted for some time whether he had before him a completely new form of electric long-range action." He was amazed that a glass plate, which under normal conditions transmitted light rays well, being placed between spark-forming electrodes, interrupted their formation.

However, in the experiment according to the scheme shown in Fig. 1, the outburst of spark flares between the ends of the secondary conductor in circuit C occurred regardless of the absence or presence of insulator B (from sulfur or paraffin) between the AA plates. Along the way, it turned out that sparking is influenced by ultraviolet radiation: the number of sparks decreased noticeably in a darkened room or when the entire installation was placed in an opaque case. Hertz was particularly embarrassed by the "transmission" of light flashes as the contour C is increasingly removed from the AA plates. Even at a distance of 12 m, he managed to see sparks in the secondary circuit.

In contrast to the established view that the waves are localized and move inside the conductor, Hertz saw that they also propagate in the surrounding space. "The claim that electric forces can exist independently of their charges was in direct contradiction with the prevailing theories of electricity." Experiments have shown that through the air the waves propagate at the same speed as along the wire. Gradually, he had to understand, "that extreme caution should be exercised here when applying general concepts and provisions stemming from the ordinary doctrine of electricity."

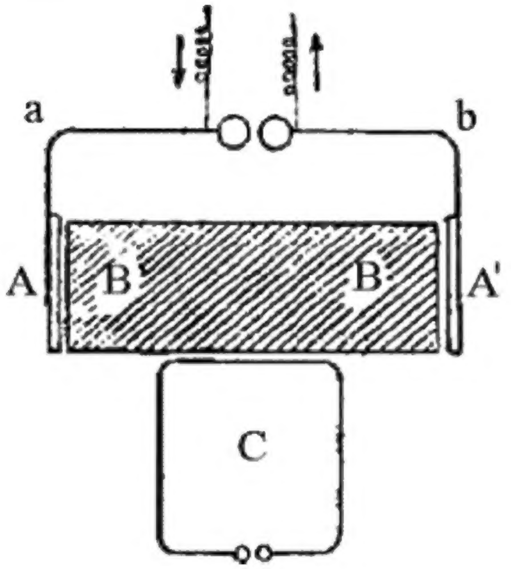

**Fig. one**

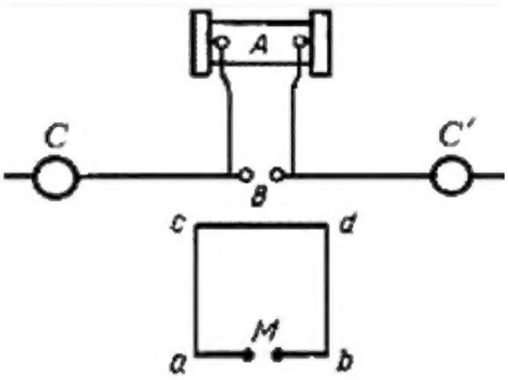

**Fig. 2**

In the years 1887-1888. in laboratory conditions, Hertz formulates methodological tasks for testing Maxwell-Faraday hypotheses, develops and makes devices, reflectors, screens for them, studies the features of the behavior and propagation of electromagnetic waves discovered by him. In a series of experiments and tests, he conducts thousands of observations and measurements of spark discharges millimeter wavelengths. In all installations and devices he uses a large Rumkorf generator coil with a length of 52 cm and a diameter of 20 cm with a mercury breaker.

The most famous print (1887) of his work "Ovesma fast electrical vibrations" [3, p. 131-148] is devoted mainly to resonance studies. In the device, the circuit of which is shown in Fig. 2, the output of the high-voltage generator A is loaded on the horizontal primary circuit of the SHS? 2.6 m long, consisting of two straight copper pieces of wire with a diameter of 5 mm with zinc hollow balls C and C mounted on the ends? with a diameter of 30 cm. In the secondary circuit, having the shape of a circle with a diameter of 1 m or square with sides 75 cm long, a wire with a diameter of 2 mm is used. Hertz checked the resonance phenomenon in various symmetrical positions of the balls C and C? on the wire when the linear emitter was removed from the secondary circuit by 30 ... 50 cm. It was indicated along the length of the spark in the secondary circuit. A pronounced resonance manifested itself with a constant length of the primary circuit, loaded at the ends with rectangles of copper wire with sides 10v20 cm and adjustable from 10 to 250 cm in length of the sides ac and bd of the secondary circuit with a constant size of 30 cm in the sides ab and cd (Fig. 3, a). For the first time in the world, the drawn resonance curve for the HF is shown in Fig. 3, b. Instead of the ac and bd conductors, Hertz also includes inductors coiled from identical copper wires with a diameter of 2 mm and the same length of 10 ... 250 cm (Fig. 3, c). The result was a slightly smoothed resonance curve (Fig. 3, d).

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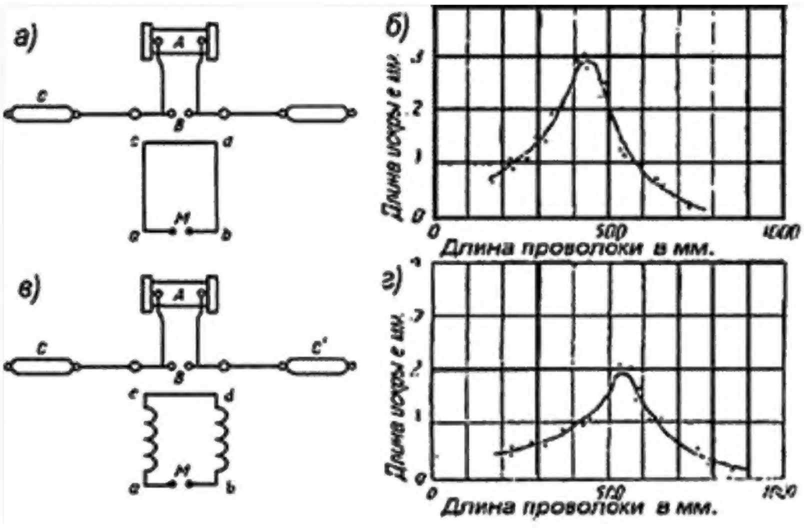

**Fig. 3**

In 1888, on an installation with a large parabolic mirror with external dimensions of 2in1.2 m, a depth of 0.7 m (made of zinc sheet) and a focal length of 12.5 cm, Hertz conducted experiments on the study of the rectilinear propagation, reflection, polarization and refraction of short electromagnetic waves with a length of about 50 cm (600 MHz). He sought to show the identity of electromagnetic and light waves and to finally prove the relevance of the Maxwell-Faraday theory. The primary chain (dipole) consisted of two copper wires elongated in a line 50 cm long and 5 mm in diameter. The dipole was placed vertically in the middle of the focal line. The secondary circuit was an annular circuit with a diameter of 15 cm, also made of copper wire with a diameter of 1 mm. Report on the work performed [3, p. 183-192] under the name "On the rays of electric force" December 12, 1888 was introduced to Helmholtz. The next day, Thursday, December 13, Hertz spoke in Berlin at a scientific conference of the Prussian Academy of Sciences [5].

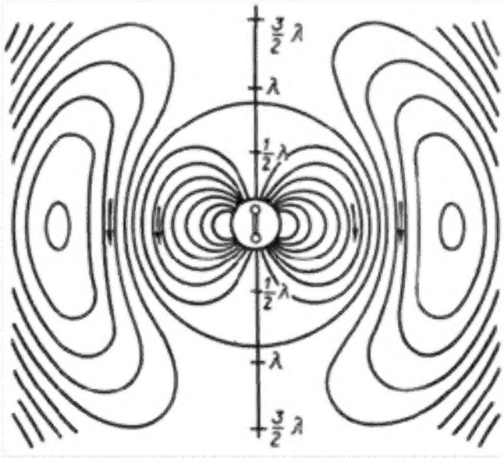

**Fig. four**

Hertz turned to the development of Maxwell's equations, his own understanding of their mathematical and physical meaning (1889) in the theoretical article “The forces of electric oscillations, considered from the point of view of Maxwell's theory” [3, p. 166-182]. In the illustrations for the article, he presented a figurative vision of the lines of propagation of electromagnetic waves from the dipole he invented, that is, perpendicular to the emitter (Fig. 4).

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